High Speed Iodine K-Edge Subtraction Angiography;
A Preliminary Experiment with Rats

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Abstract: Using the high speed iodine K-edge subtraction system, good images of small arteries of the rat can be demonstrated sequentially after the venous injection of contrast material. The arteries of about 0.3–0.4 mm in diameter can be seen. The image quality appears to be better than that obtained by conventional DSA.

This is the first report that the sequential arterial images were actually obtained by using two dimensional iodine K-edge subtraction system with synchrotron radiation.

INTRODUCTION

The selective coronary angiography is the final diagnostic modality for the ischemic heart disease. But this modality is invasive and costly because a specific catheter must be directly inserted into coronary artery using a special cine-angiographic system. On the other hand, Rubenstein E. revealed that using the iodine K-edge energy subtraction angiography, coronary artery would be demonstrated with transvenous injection of the contrast material [1–3]. They are now trying to perform the human study by using line scanning method at the Stanford Synchrotron Radiation Laboratory (SSRL) [4]. And same studies are being tried in DESY and Soviet [5, 6]. In Japan, two dimensional image acquisition system is now being constructed [7–10]. In this paper, the results of the rats' experiment which was obtained by the high speed iodine K-edge subtraction angiographic system, will be described.

METHOD

The high speed K-edge subtraction system consists of movable silicon (111) monocrystal, image intensifier (II) and TV camera (9 inch II, Thomson TH 9428 E and Hitachi DFA–II type TV (S/N 57 dB)), and digital memory system. Image processing and control of the system are performed by the computer (HD-68000 as a micro processor unit). This system is made at beam line of 8 C of Photon Factory, Tsukuba. The slightly different energies of the beams are produced by diffracting the synchrotron radiation from rotating the silicon

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(Received Aug. 26, 1988 and Accepted Sep. 16, 1988)

Key words: iodine K-edge, energy subtraction angiography, synchrotron, radiation, animal experiment, dynamic image acquisition
monochromator crystal, approximately 0.1°. The energy of the beams is adjusted in such a way that one is 250 eV above the iodine K-edge and the other is 250 eV below the K-edge. Further asymmetric reflection at silicon planes expanded the beam size 25 times, produces 50 × 60 mm² monochromatic X-ray beam (Fig. 1). Photon energy between above and below iodine K-edge is changed within 16.7 msec. And 16 frames of subtracted image were obtained sequentially. The time interval of each image was set about 550 msec. For the digital processing, X-ray TV images are digitized using an 8 bit AD converter, into 256×256 pixel matrices with an 8 bit depth.

During this experiment, the electron storage ring is operated at 2.5 GeV with a typical current of approximately 200 mA. The incident monochromatized flux is about 7.4 × 10⁷ photons/second/mm².

The rats were anesthetized with phenobarbital and 24 G (0.7 mm) angiocatheter was inserted into tail vein. 1.5 ml/kg of contrast material (conraxin H 80%) was injected by the injector at the rate of 0.75 ml/kg/sec. The averaged body weights of the rat were about 400 gram, and body widths were about 3 cm. TV images were obtained 4 sec after the starting point of the injection. Transvenous angiograms were carried out in the two positions: an anterior and a 30 degree left anterior oblique position (Fig. 2).
Fig. 3 The images of above and below iodine K-edge, and subtracted image at the arterial phase in the thorax.

Fig. 4 The sequential iodine K-edge subtracted images in the thorax.

The actual time interval of each image is 550 milli second. But image of this figure is shown as every other frame, i.e. 1.1 second interval.

The conventional DSA system (Digitifomer X, Toshiba) was used for the comparison study. This DSA system consisted of 9 inch II-TV (60 dB) and 10 bit AD converter. X-ray TV image were digitized into 512×512 pixel matrices and an 8 bit depth. The condition of image acquisition was set as 60 kVp with 50 mA. And to avoid the halation, acryl plate of
RESULTS

At the thorax and abdomen, the K-edge subtracted images were obtained clearly. **Fig. 3** shows the typical image of above and below iodine K-edge, and subtracted image in the

70 mm thickness was used.
arterial phase. The sequential subtracted images are shown in Fig. 4. In the first frame, contrast material was seen in the inferior vena cava, right atrium and right ventricle. The second frame image showed pulmonary arteries. In the next frame, lungs were perfused remarkably. In the fifth frame image, the common carotid, subclavian arteries, and aorta were demonstrated clearly. And the contrast material was washed out gradually. In the abdomen, both renal arteries and superior mesenteric artery were shown clearly (Fig. 5). The arteries of about 0.3-0.4 mm in diameter could be revealed. The quality of the images were better than that obtained by the conventional DSA (Fig. 6). DSA image showed only blurred common carotid and subclavian arteries under the marked quantum noise.

DISCUSSIONS

The preliminary experiment with rat indicates that the high speed iodine K-edge subtraction system with synchrotron radiation (SR) as a source, provides better sequential images of small arteries after peripheral venous injection of contrast material. The significant misregistration artifacts are not produced by the respiration or bowel movement because of high speed K-edge switching and image acquisition. But the overall dimensions of coronaries of the rat were very small along with overlapping of opacified structures like atria and ventricles, and this contributed to non-visualization of these arteries.

The conventional DSA images showed a significant background quantum noise, and the image contrast between arteries and background was poor comparing with that obtained by synchrotron radiation K-edge subtraction image. The image was not acquired in the same condition between SR K-edge subtraction angiographic system and the conventional DSA, but image quality obtained by SR K-edge subtraction system appears to be good. The reason of
this might be due to the following facts:

1) The sensitivity of conventional X-ray imaging system is low to iodine-containing agents, because X-ray tube emits radiation over a broad spectrum. Whereas the contrast resolution of low iodine containing artery is significantly improved by the iodine K-edge subtraction procedure (Fig. 7). The iodine sensitivity is larger than that for soft tissue and bone by the factors of $1.7 \times 10^4$ and $3.9 \times 10^4$ respectively ($33.164\text{ keV} \pm 8.5\text{ eV}$) [1].

2) X-ray intensity may be adequate to record images at the most iodine sensitive energy. Synchrotron radiation has a enormous intensity and a continuous spectrum. And by Bragg-diffraction, a narrow band of energy with strong intensity can be selected.

3) The scatter is little because scatter rejection can be done by an efficient air gap distance between objects and image intensifier. The scatter level may decrease less than 1% [11]. This scatter rejection improves the contrast of low-contrast object.

4) The spatial resolution is excellent because of parallel X-ray beam. Whereas X-ray tube emits radiation into a cone of large solid angle, and beam expands markedly and is not parallel. In addition, this character also disturbs the use of air gap method described above.

5) Image display is done at very narrow window-level in conventional DSA because of a very low image contrast between arteries and background. This may also enhance the background noise of the image.

The transvenous angiogram is performed with the catheter tip in the peripheral (tail) vein. The contrast material, therefore, remained in the inferior vena cava in the delayed images also. These concentrations were not sufficient as compared to the injection in central venous system, which would have revealed much smaller arteries in the thorax and abdomen.

But at present, the image definition of this initial study is not of clinically significant quality and needs improvement; such improvement is expected to be obtained by increasing a signal-to-noise ratio with high X-ray fluence (using a wiggler beam or TRISTAN Accumulation Ring), using much better AD converter and TV system ($512 \times 512 \times 8$ bit). For this purpose, a special K-edge subtraction system for coronary arteriogram are now going to be constructed by Akisada and their colleague [7-9].

In USA and Europe, images are being acquired on a line-by-line scan using a fan X-ray beam. But in our system, images were acquired as having two dimensions using II-TV system. So the sequential images can be obtained as the conventional cine-angiography. This is the first dynamic image of its kind obtained in the world.

**ACKNOWLEDGMENT**

This work was performed under the approval of the Photon Factory Program Advisable Committee (Proposal No. 87-189).

**REFERENCES**


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